INSTITUTO LATINOAMERICANO DE
CIENCIAS DE LA VIDA Y LA NATUREZA

PROGRAMA DE POSGRADO EN
BIODIVERSIDAD NEOTROPICAL

VARIACIÓN EN LA DIVERSIDAD DE LA VEGETACIÓN DE LA VERTIENTE ORIENTAL DE LA SIERRA DE QUILMES (DESIERTO DEL MONTE) A LO LARGO DE UN GRADIENTE ALTITUDINAL

ALEJANDRA BELÉN DIP

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Disertación de maestria presentada al programa de Posgrado em Biodiversidad Neotropical, del Instituto Latinoamericano de Ciencias de la Vida y la Naturaleza, de la Universidad Federal de la Integración Latinoamericana, como requisito parcial para la obtención del título de Máster en Ciencias Biológicas

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Ficha catalográfica

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DIP, Alejandra Belén. Variação na diversidade da vegetação nas encostas orientais da Serra de Quilmes (Deserto do Monte) ao longo de um gradiente altitudinal. 40 p. Dissertação de mestrado do Programa de Pós-Graduação em Biodiversidade Neotropical – Universidade Federal da Integração Latino-Americana, Foz do Iguaçu, 2019.

RESUMO

*No presente trabalho avaliamos a variação na composição e diversidade vegetal ao longo de um gradiente altitudinal de 1650 a 2550 msnm, nas encostas orientais da Serra de Quilmes (Deserto do Monte), nas quais a principal formação vegetal é a estepe arbustiva de xerófila. Foram delimitadas cinco franjas altitudinais e, em cada uma, foram dispostas oito unidades amostrais (três transectos de 70 m, paralelos e distantes 15 m um do outro; amostragem por ponto intercepto)**.** Os padrões de diversidade de espécies e diferenciação e padrões de abundância de formas de crescimento foram analisados ao longo do gradiente altitudinal. No total, 123 espécies, pertencentes a 33 famílias foram registradas nas 40 unidades amostrais. Plantas herbáceas representaram quase 55% das espécies amostradas, arbustivas e subarbustivas 26.4%, suculentas 8.8% e arbóreas 7.2%. A abundância de árvores apresentou uma correlação negativa com a altitude, enquanto a de arbustos apresentou uma correlação positiva. Não foi possível realizar a classificação das bandas altitudinais com base na diversidade gama, pois seus perfis de diversidade se cruzaram. Apenas a franja 1900 foi consistentemente menos diversa do que as demais. O modelo com melhor ajuste para a relação entre diversidade alfa de ordem 0 e altitude foi um modelo linear simples, enquanto para a diversidade de orden 1 e 2, o melhor ajuste foi de modelos polinomiais de grau 3. Os modelos de diversidade alfa de lenhosas de ordem 1 e 2 apresentaram os valores mais altos de R^2. Quase todos os modelos foram significativamente diferentes dos modelos nulos, mas eles apresentaram valores de R^2 baixos, indicando pouco ajuste aos dados. A dissimilaridade entre franjas foi mais alta que a dissimilaridade entre as amostras de cada banda. A distribuição das unidades amostrais ao longo do eixo NMDS1 reflete a diferenciação gradual das comunidades ao longo do gradiente. Estudos adicionais são necessários para entender como fatores relacionados com a altitude e fatores independentes da altitude interagem e afetam os padrões de diversidade da vegetação do Deserto do Monte.*

Palavras-chave: *Vegetação de deserto, diversidade alfa, diversidade beta, montanhas áridas*

DIP, Alejandra Belén. Variación en la diversidad de la vegetación de la vertiente oriental de la Sierra de Quilmes (Desierto del Monte) a lo largo de un gradiente altitudinal. 40 p. Disertación de maestría del Programa de Postgrado en Biodiversidad Neotropical - Universidad Federal de la Integración Latinoamericana, Foz do Iguaçu, 2019.

RESUMEN

En el presente estudio evaluamos la variación en la composición y diversidad vegetal a lo largo de un gradiente altitudinal de 1650 a 2550 msnm, en la vertiente oriental de la Sierra de Quilmes (Desierto del Monte), cuya principal formación vegetal son las estepas arbustivas de xerófilas. Se establecieron cinco bandas altitudinales y se realizaron muestras en ocho sitios en cada una de ellas (método del punto intercepto, sobre tres transectos de 70 m paralelos y distantes 15 m entre sí). Se analizaron los patrones de diversidad y diferenciación de la comunidad vegetal y los patrones de abundancia en formas de crecimiento a través del gradiente altitudinal. Fueron registradas 123 especies pertenecientes a 33 familias en las 40 unidades de muestreo. Las herbáceas representaron casi el 55% de las especies, las arbustivas/subarbustivas el 26.4%, las suculentas el 8.8% y las arbóreas el 7.2%. La abundancia de árboles mostró una correlación negativa con la altitud, mientras la abundancia de arbustos/subarbustos mostró una correlación positiva. Las bandas altitudinales no pudieron ser clasificadas con base en su diversidad gama, ya que sus perfiles de diversidad se intersectaron; sólo la banda 1900 fue consistentemente menos diversa que las demás. El modelo con mejor ajuste para la relación entre diversidad alfa de orden 0 y la altitud fue un modelo lineal simple, mientras para la diversidad de orden 1 y 2 mostraron mejor ajuste modelos polinomiales de tercer grado. Los modelos de diversidad alfa de orden 1 y 2 de leñosas presentaron los valores más altos de R^2. Casi todos los modelos fueron significativamente diferentes de modelos nulos, pero casi todos ellos presentaron valores bajos de R^2 indicando un pobre ajuste a los datos. La disimilitud entre bandas fue más alta que la disimilitud entre las muestras de cada banda. La distribución de las unidades de muestreo a lo largo del eje NMDS 1 refleja que la diferenciación entre las comunidades sucede gradualmente a través del gradiente. Se requieren estudios adicionales para entender cómo factores relacionados con la altitud y factores independientes de la altitud interactúan entre sí y afectan los patrones de diversidad de la vegetación del Desierto del Monte

***Palabras clave**: Vegetación de desierto, Diversidad alfa, Diversidad beta, montañas áridas*

DIP, Alejandra Belén. ***Plant diversity patterns in Sierra de Quilmes (Monte Desert) along an altitudinal gradient.*** *2019. 40 p. Master's thesis of the Graduate Program in Neotropical Biodiversity - Federal University of Latin American Integration, Foz do Iguaçu, year.*

ABSTRACT

In this study we evaluated the variation in plant composition and diversity along an altitudinal gradient from 1650 to 2550 m.a.s.l., on Sierra de Quilmes eastern slope (High Monte Desert), which main plant formation is xerophytic shrubs steppes. Five altitudinal bands were established, and eight sites were sampled in each one of them. We analyzed plant community diversity and differentiation patterns and growth form abundance patterns along the altitudinal gradient. A total of 123 species belonging to 33 families were found in the 40 sampling units. Herbaceous plants represented almost 55% of the species, shrubs and subshrubs 26.4%, succulents 8.8%, and trees the remaining 7.2%. The abundance of trees showed a negative correlation with altitude, while the abundance of shrubs was positively correlated. Bands couldn't be ranked based on their gamma diversity because their diversity profiles intersected, only band 1900 was consistently less diverse. Simple linear models better fitted to alpha diversity of order 0, while third degree polynomial models better fitted to alpha diversity of order 1 and 2. Woody plants alpha diversity of order 1 and 2 models presented the highest R^2 values. Almost all models were found to be significantly different from null models, but most of them present very low values of R^2 indicating poor fit to the data. Dissimilarity among bands was found higher than dissimilarity within bands. The arrangement of sampling units along the NMDS 1 axis reflects that communities differentiation occurs gradually along the altitudinal gradient. Further studies are required to understand how factors correlated with altitude and factors independent of altitude interact with each other and affect vegetation patterns of diversity in Monte Desert.

Keywords*: Desert vegetation, Alpha diversity, Beta diversity, Arid mountain*

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SUMARIO

1 INTRODUCCIÓN

En el trabajo científico que presento a continuación realicé una evaluación de los patrones de diversidad vegetal a través de un gradiente altitudinal en un área de desierto perteneciente a la Ecorregión del Monte de Sierras y Bolsones. Se trata de una región con grandes áreas afectadas por un grado de desertificación de moderado a grave y sometida a diversas perturbaciones entre las que destacan el sobrepastoreo de ganado, los incendios, la tala de árboles y arbustos. Por ser tradicionalmente considerado un ambiente de bajo valor ecológico y económico, un “Chaco empobrecido”, solo 4% de su territorio se encuentra bajo algún tipo de protección en el Sistema de Áreas Naturales Protegidas. Además, como otros desiertos del mundo, sustenta diversas poblaciones humanas, en general empobrecidas, que en muchos casos dependen, al menos parcialmente, de su ambiente más inmediato para la obtención de recursos. Sin embargo, los estudios ecológicos de la vegetación en esta región son escasos.

Caracterizar los patrones de la diversidad vegetal y comprender los procesos que los generan es necesario para proponer medidas adecuadas de manejo. En el Desierto del Monte, las variaciones en la composición y estructura vegetal entre las distintas unidades geomorfológicas y en diferentes posiciones topográficas habían sido descritas, pero no analizadas cuantitativamente en búsqueda de patrones de diversidad. Para realizar esta evaluación consideré que el gradiente altitudinal era un abordaje adecuado por ser el gradiente más conspicuo en el área de estudio, el más claramente observable y mensurable, y que abarca una serie de factores ambientales que varían con él y son relevantes para la vegetación. Este gradiente es frecuentemente utilizado como herramienta heurística y experimento natural para evaluar la respuesta de los seres vivos a los cambios en el ambiente.

Muchos desiertos del mundo se encuentran en zonas de montaña debido al efecto de sombra de lluvia que éstas producen. Mientras la ladera expuesta a los vientos predominantes recibe las precipitaciones, la ladera opuesta constituye una zona árida. Por este motivo, otros trabajos previamente utilizaron los cambios de altitud y su relación con variables ambientales para la comprensión de los patrones de diversidad de la vegetación de zonas áridas y semi-áridas.

En el presente trabajo se evaluó la variación en la composición y diversidad vegetal, así como la variación en las formas de crecimiento, a través del gradiente altitudinal de la vertiente oriental de la Sierra de Quilmes, en el norte del Monte de Sierras y Bolsones.

El objetivo fue reconocer patrones de diversidad y determinar si la altitud puede servir como predictor de la diversidad.

Se realizaron muestreos de vegetación en cinco bandas altitudinales en las que se registró la abundancia de todas las especies vegetales presentes. Se analizaron los patrones de abundancia de formas de crecimiento, de diversidad de especies y de diferenciación a través del gradiente altitudinal. En la siguiente sección se presenta el manuscrito del artículo que será presentado en Journal of Arid Environments. Los resultados son comentados brevemente en las consideraciones finales.

2. ARTÍCULO CIENTÍFICO

PLANT DIVERSITY PATTERNS IN SIERRA DE QUILMES (MONTE DESERT) ALONG AN ALTITUDINAL GRADIENT

Dip, Alejandra Belén. Sampietro Vattuone, María Marta. Eleuterio, Ana Alice.

Abstract. In this study we evaluated the variation in plant composition and diversity along an altitudinal gradient from 1650 to 2550 m.a.s.l., on Sierra de Quilmes western slope (High Monte Desert), which main plant formation is xerophytic shrubs steppes. Five altitudinal bands were established, and eight sites were sampled in each one of them. We analyzed plant community diversity and differentiation patterns and growth form abundance patterns along the altitudinal gradient. A total of 123 species belonging to 33 families were found in the 40 sampling units. Herbaceous plants represented almost 55% of the species, shrubs and subshrubs 26.4%, succulents 8.8%, and trees the remaining 7.2%. The abundance of trees showed a negative correlation with altitude, while the abundance of shrubs was positively correlated. Bands couldn't be ranked based on their gamma diversity because their diversity profiles intersected, only band 1900 was consistently less diverse. Simple linear models better fitted to alpha diversity of order 0, while third degree polynomial models better fitted to alpha diversity of order 1 and 2. Woody plants alpha diversity of order 1 and 2 models presented the highest R^2 values. Almost all models were found to be significantly different from null models, but most of them present very low values of R^2 indicating poor fit to the data. Dissimilarity among bands was found higher than dissimilarity within bands. The arrangement of sampling units along the NMDS 1 axis reflects that communities differentiation occurs gradually along the altitudinal gradient. Further studies are required to understand how factors correlated with altitude and factors independent of altitude interact with each other and affect vegetation patterns of diversity in Monte Desert.
Key words: desert vegetation, alpha diversity, beta diversity, arid mountain

Introduction

Arid and semiarid environments, characterized by water scarcity and low soil productivity, are particularly vulnerable to impacts derived from human activities. Erosion caused by wind and water, salinization and contamination due to irrigation and changes in plant composition are the main causes of soil degradation (Navone & Abraham, 2006). The biodiversity they support has a great value when phylogenetic and biogeographic aspects are considered (Kakakhel 2006, Roig et al. 2009), and its loss threatens the provision of ecosystem services, such as erosion control, or food and water supply, which are scarce in these environments (Reynolds et al. 2007, Bangash et al. 2007). Perennial vegetation loss in arid and semi-arid regions is considered an important ecological threat. According to catastrophic shifts theory, vegetated and desert situations may represent alternative stable

states, so that recolonization of desert by perennials could be very difficult once a certain threshold has been overcome (Scheffer et al. 2001). Therefore, understanding the ecological processes that sustain desert vegetation is central to an adequate landscape management, and to achieve this, recognizing and characterizing plant diversity patterns is first necessary.

The Monte Desert, located in western Argentina, constitutes the most arid rangeland in the country (Abraham et al. 2009), with large areas exhibiting a moderate to severe degree of desertification (Villagra et al. 2009). Some previous studies on Monte vegetation, particularly High Monte ecoregion (Olson 2001) include descriptions of the main plant communities in Santa María Valley and their relationship with weather and soils (Morello 1951, 1958, Escudero Martinez 1991). These studies describe compositional changes in plant communities along geomorphological units and topographical positions. According to Bisigato (et al. 2009), communities occupying different positions along the slope and soil texture gradients in High Monte alluvial fans vary in cover percentage and in diversity, both increasing with increasing elevation. The first analysis of structure and plant composition in association with environmental variables applying statistical tools corresponds to a hyper-arid sector of the Monte (Acebes et al., 2010). Anyway, ecological studies on the vegetation of this region are scarce, and we found no previous studies assessing High Monte plant diversity patterns.

Topographic heterogeneity contributes to the formation of deserts, because of the “rain shadow” generated by mountains, especially in the tropics, but also in higher-latitude regions. Windward slopes of these mountains are covered by cloud forests, while leeward slopes and adjacent lands are covered by arid scrub (Ezcurra et al. 2006). This is the case in High Monte, where precipitation amounts are limited by the shadow effect produced by Sierras Pampeanas, which restrain the flow of Atlantic air (Abraham et al. 2009). High Monte is restricted to longitudinal valleys and nearby mountain slopes (Bisigato et al 2009). Rainfalls, infiltration and runoff rates, erosion and sedimentation rates, as well as radiation are not uniform in the landscape, varying along slopes and piedmonts and generating gradients in soil texture, water availability, and temperature. Interactions of all these factors contribute to the heterogeneity in species composition (Bisigato et al. 2009). Also, they are all related in different and sometimes complex ways with the altitudinal gradient. This gradient has been frequently used as heuristic tool and “natural experiment” to assess the organisms’ response to environment, and species diversity variation along it is an ecological pattern broadly recognized (Korner 2007, Lomolino 2001). Thus, this gradient is a good starting point to assess plant diversity patterns, and subsequently relate them with relevant

environmental variables, such as edaphic and climatic ones.

Diversity variation patterns along an altitudinal gradient depend on the taxon studied, but the most reported patterns are monotonic decreases in diversity with altitude, and hump-shaped curves with diversity peaks at different altitudes (Nogués-Bravo et al. 2008). The last one is the most frequent pattern reported in plant studies (McCain & Grytnes 2010). This happens because some climatic variables vary in a predictable way with elevation, as they are physically associated with it (temperature, atmospheric pressure, solar radiation), while others vary in more complex ways that depend on local or regional climate conditions (precipitation, humidity, seasonality) (Korner 2007, McCain & Grytnes 2010). The most common precipitation pattern observed in temperate mountains and arid regions, such as the Monte Desert, our study site, is a direct relationship between elevation and plant productivity, regardless of latitude (Rosenzweig 1968, Sanders 2002). Diversity peaks are then expected to occur in the altitudinal bands that combine the optimal conditions for the studied group (Lomolino 2001).

Our aim in this study was to analyze plant community diversity and differentiation patterns along an altitudinal gradient in a portion of Santa Maria Valley, in northern High Monte. We want to find out whether diversity conforms to usually reported altitudinal patterns of plant diversity, and whether altitude is a good predictor of changes in diversity for our study area.

Methods

Study area. Santa María valley is part of the Monte Desert. It belongs to the High Monte ecoregion (Olson et al. 2001), called *Monte de Sierras y Bolsones* in Argentina (Bukart et al., 1999; Pol et al., 2005), and occupies part of Catamarca, Tucuman and Salta provinces territories. It is a South-North oriented valley of around 120 km long and 30 km wide, limited by Sierra de Quilmes (4720 m.a.s.l.) to the west and Sierra de Aconquija (4600 m.a.s.l.) and Cumbres Calchaquíes (4760 m.a.s.l.) to the east. Santa María River flows along the bottom of the valley with an average altitude of 1700 m.a.s.l. and receives the waters of both sides. The study area is located in the middle section of the western side of this valley, including the Sierra de Quilmes slope and piedmont (-66.1130 -26.5042; -65.9421 -26.3293; Tucumán Province) (Fig. 1). Annual rainfall averages 200 mm and is concentrated during summer, while the average annual temperature reaches 15-16º C (Peña Monné & Sampietro Vattuone 2016).

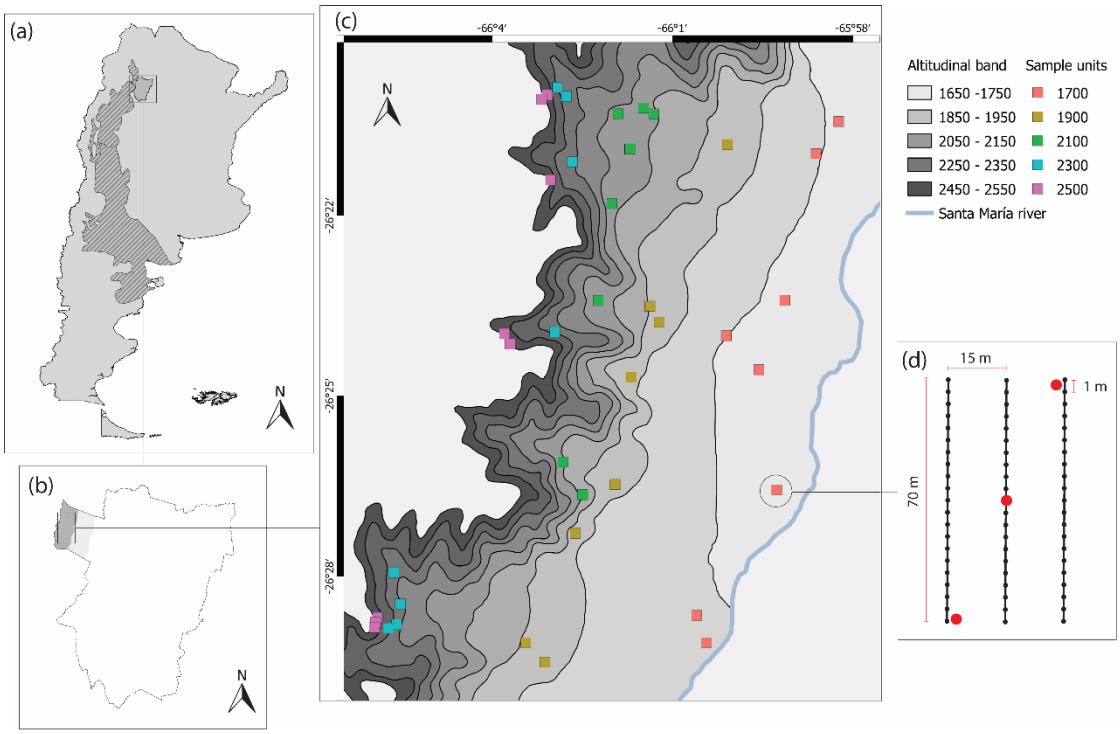

Fig. 1. Study area location: (a) Argentina. The shaded area represents the extension of Monte Desert; (b) Tucumán province. The shaded area is the part of the province occupied by Monte Desert, while the darker shade indicates the eastern slope of Sierra de Quilmes; (c) Study area, located on the western sector of Santa María Valley, with contour lines delimiting the altitudinal bands. Sampling sites location are also represented; (d) Sampling design in each site: three lineal transects of 70 m long, over which the vegetation was recorded by point intercept method, every 1 m distance.

Soils are generally sandy, poorly developed, shallow, and have scarce or no horizons differentiation (Puchulu & Fernández 2014). Geologically, Sierra de Quilmes is composed by granites and schists from Puncoviscana Fm. (Precambrian-Lower Cambrian, Ruiz Huidobro, 1972). The area is composed by two main geomorphological units: Sierra de Quilmes' slopes and piedmont (Peña-Monné & Sampietro-Vattuone, 2016).

The study area is part of the Monte phytogeographical province. Two main plant communities can be distinguished: shrub steppes of xerophytes and cacti, and carob (*Prosopis*) forests. These forests grow in areas where permanent water table is available, normally in the banks of Santa María River and its main tributaries, or in depressions with shallow phreatic mantles (Morello 1951, Cabrera 1971). In addition to these main formations, other edaphic communities are covering salty or sandy soils (Morello 1951, Cabrera 1971).

Vegetation sampling. This study evaluates plant diversity changes along an altitudinal gradient. Plant communities found in xerophytic and cacti steppes were sampled. Other azonal plant communities, such as Prosopis forest, were excluded from the analysis. Sampling was restricted to areas less disturbed by grazing. Such areas were identified

based on pedestrian surveying and inquiring to local people about land use. With this information and considering vegetation physiognomy (Morello, 1958) the study area was classified into five altitudinal bands of 100 m separated between them by 100 m of altitude: 1650-1750, 1850-1950, 2050-2150, 2250-2350, and 2450-2550 m.a.s.l. (they will be named from now on by their central altitude value 1700, 1900, 2100, 2300 and 2500, respectively). The gradient covered reaches the altitudinal limit between Monte and Prepuna phytogeographical provinces, at about 2400 m.a.s.l. (Escudero-Martinez 1991).

Sampling was performed in January and February of 2018, during rainy season, when perennial and annual plants are present. Eight samples were taken from each band, totalizing 40 samples, taking care of leaving a minimal distance among them and from human settlements of at least 1 km. A minimum distance from human settlements was established to diminish effects of plant and wood collection, and grazing. Each sampling plot consisted of three linear transects of 70 m long separated by 15 m from each other and traced in the same direction of the slope. Transects were marked on 1 m intervals, totalizing 213 sampling points per sampling unit. The Point Intercept Method was used along linear transects (Elzinga et al., 2001, Nunes et al., 2014) to obtain a measure of species abundance. This method, initially proposed by Goodall (1953) for grasslands studies, proved to be less time consuming, and more accurate in the quantification of herbaceous species from semi-arid regions than others based on area, such as the modified Whittaker method (Nunes et al., 2014). A 0.5 cm diameter stick was placed perpendicularly to the soil surface on each mark, and plant species that contacted the stick were recorded, so that the abundance of each species is represented by an absolute value, where unit is “stick contact”. Only epiphytes were not considered. Geographical coordinates of the southeast corner of each sampling unit and its altitude were recorded using the mobile app *GPS Status & Toolbox*.

Data processing and analysis. Plant species were identified and classified by family and by growth form using field guides (Ábalos 2016, Kiesling & Ferrari 2015), research papers (Ceballos & Perea 2014, Morello 1958), digital herbariums (Zuloaga et al. 2019), and comparison with specimens from the Phanerogamic Herbarium of Miguel Lillo Foundation. We based the classification in growth forms in Argentinian Flora of Darwinion Botanical Institute (Zuloaga et al. 2009). Original categories included: herb, shrub, shrub/subshrub, subshrub, succulent herb, succulent subshrub, succulent tree, Tree, tree/shrub, and vine. For growth form analysis we merged them into four categories: herbaceous (including herbs and vine, as the only vine species we sampled was a non-woody one), shrub/subshrub (including shrub, shrub/subshrub and subshrub categories), tree (including tree and

tree/shrub category) and succulent (including succulent trees, succulent herbs and succulent subshrubs). Some diversity analysis were performed for all species and for woody and herbaceous species separately. In those cases, tree and shrub/subshrub categories were merged into woody category and succulents were reassigned as appropriate (succulent herbs in herbaceous category and succulent trees and subshrubs in woody category).

The association between growth forms abundance and altitude was assessed with Spearman's rank correlation. Diversity was analyzed following the classification proposed by Tuomisto (2010). Following her, we only refer as "diversity" to what we measure as effective numbers of types. Alpha diversity (D_α) is the diversity of each sample site; band gamma diversity (D_γ) is the diversity of each altitudinal band, which is the pooled diversity of the eight sampling units; band beta diversity (D_β) is the ratio of D_γ to total D_α (the average of D_α the band's eighth sampling units). In this study context, D_β is an effective number of sampling units, i.e., the number of equally weighted sampling units with no species in common necessary to equal the observed diversity. We also explored species differentiation among altitudinal bands, though we do not refer to these measures as beta diversity as we do not use effective numbers of types.

We used Hill numbers (Hill 1973), also called equivalent or effective numbers of species, as diversity metrics. They represent the number of equally abundant species that would make up a theoretical community with the same complexity of the observed community (Jost & González Ojeda 1012). Hill numbers are calculated by the expression

$$qD \equiv \left[\sum pi^q\right]^{\frac{1}{1-q}}$$

in which ${}^qD$ is the effective number of species of order q; p_i is the relative abundance of species i; and q is the order of diversity, and it determines the weight given to rare species. For the calculation of diversity of order 0 (${}^0D$), equal weight is assigned to all species present in the community, i.e. ${}^0D$ is equivalent to species richness. For the calculation of diversity of order 1 (${}^1D$, when q tends to 1, once when $q = 0$ the equation is not defined) each species is weighted according to its relative abundance, and ${}^1D$ is equivalent to the exponential of the Shannon index. For the calculation of diversity of order 2 (${}^2D$), disregards rare species are disregarded, so ${}^2D$ is equivalent to the Gini-Simpson index. Thereby, q values below 1 assign to rare species a higher weight, and q values above 1 assign higher weight to dominant species (Jost & González Ojeda 2012).

Diversity profiles were generated using the information obtained from these diversity metrics to allow a visual comparison of diversity values considering a spectrum of possible weights assigned to rare species. We compared band gamma diversities using the diversity profiles built for all plant species, and for woody and herbaceous plant species separately. The profiles were calculated for *q* values between 0 and 2, with intervals of 0.1 and using pooled data of the individual sampling plots corresponding to each altitudinal band. Values of band total alpha, beta and gamma diversity of order 0, 1 and 2 were calculated. The relationship between altitude and alpha diversity of all plants, woody plants and herbs was assessed by fitting simple linear or polynomial regressions with *lm* function, after log-transforming to achieve normal distribution if necessary. We used *anova* to compare the fit of these models with the fit of null models and to compare models with each other. Simpler models were preferred over more complex ones if there were no difference between them in their fit to observed data.

We performed an NMDS ordination to graphically represent species differentiation between sampling units and to evaluate the arrangement of the sample units along the altitudinal gradient. NMDS was based on Horn dissimilarity index. This index ranked second in Barwell et al. (2015) revision of abundance-based measures of beta diversity in terms of performance, considering a series of desirable conceptual and sampling properties. It was chosen because, just as diversity of order 1, it is related with Shannon entropy. Therefore, it weights species according to their relative abundance. ANOSIM Analysis of Similarities was used to test the difference between altitudinal bands regarding their species composition. This nonparametric analysis, applied to ranked similarity matrices, tests if compositional dissimilarities between the bands are greater than those within the bands, i.e. between sampling units making up each band (Magurran 2003). All statistical analysis was performed in *R version 3.4.4* (R core team 2018). Packages employed were *vegan* (Oksanen et al. 2007), *entropart* (Marcon & Hérault 2015) and *ggplot2* (Wickham 2009) for creating the graphics.

Results

A total of 123 species belonging to 33 families were found in the 40 sampling units (Tab. 1). The families with the highest number of species were Poaceae (13), Cactaceae (12), Asteraceae (11), Solanaceae (11) and Fabaceae (9). These families together represented about 46% of the species observed. Half of the families (16) were represented by only one species. Three families accounted for about 65% of the abundance: Fabaceae (1305), Poaceae (1299) and Asteraceae (1015). Seven species were not identified, they

Tab 1. Most abundant plant species recorded along an altitudinal gradient in Sierra de Quilmes (Argentinian Monte Desert) sampled by family and ranked by decrescent abundance. Species abundance in each altitudinal band is also reported (1650-1750, 1850-1950, 2050-2150, 2250-2350, 2450-2550 m.a.s.l., named by their mean altitudinal value, 1700, 1900, 2100, 2300, and 2500 m.a.s.l. respectively)

Family	Total ab.	Species	Total Ab.	1700	1900	2100	2300	2500
Fabaceae	1305	*Prosopis torquata*	519	59	259	144	56	1
		Arquita trichocarpa	466	0	48	135	178	105
		Senna aphylla	179	67	73	21	18	0
		Prosopis nigra	75	47	7	15	3	3
		Parkinsonia praecox	37	29	4	3	1	0
		Prosopis alba	20	0	3	17	0	0
		Geoffroea decorticans	6	6	0	0	0	0
Poaceae	1299	*Aristida adscensionis*	767	6	292	231	109	129
		Jarava sp.	242	0	0	22	67	153
		Bouteloua aristidoides	143	46	75	4	3	15
		Pappophorum phillippianum	92	5	21	20	6	40
		Sporobolus maximus	16	16	0	0	0	0
		Tragus andicola	13	4	1	5	1	2
		Muhlenbergia asperifolia	9	0	3	4	2	0
		Munroa argentina	5	0	2	2	0	1
		Setaria parviflora	3	0	0	3	0	0
		Digitaria californica	3	0	0	1	0	2
		Eragrostis cilianensis	3	0	0	2	0	1
Asteraceae	1015	*Flourensia fiebrigii*	482	0	0	0	87	395
		Gochnatia glutinosa	200	0	0	0	134	66
		Pectis sessiliflora	110	4	16	63	11	16
		Austrobrickellia patens	83	0	0	0	31	52
		Baccharis salicifolia	81	11	0	0	13	57
		Bidens subalternans	35	3	1	4	12	15
		Zinnia peruviana	12	0	0	3	5	4
		Bidens sp.	5	0	0	0	5	0
		Senecio pinnatus	4	0	0	1	1	2
Zygophyllaceae	711	*Bulnesia schickendantzii*	699	65	153	263	196	22
		Tribulus terrestris	7	2	2	0	0	3
		Larrea cuneifolia	5	2	3	0	0	0
Cactaceae	241	*Opuntia sulphurea*	91	17	31	28	9	6
		Trichocereus terscheckii	82	1	5	15	10	51
		Tunilla corrugata	23	0	2	0	12	9
		Acanthocalycium thionanthum	11	0	2	5	2	2
		Gymnocalycium spegazzinii	11	3	5	3	0	0
		Cereus aethiops	7	2	3	2	0	0
		Parodia microsperma	7	0	0	1	3	3
		Gymnocalycium saglionis	5	1	1	3	0	0
Acanthaceae	174	*Justicia xylosteoides*	95	2	8	29	56	0
		Justicia tweediana	79	0	0	0	61	18
Solanaceae	140	*Lycium tenuispinosum*	124	21	24	21	54	4
		Nicotiana glauca	4	4	0	0	0	0
Chenopodiaceae	131	*Suaeda divaricata*	131	131	0	0	0	0
Pteridaceae	82	*Myriopteris myriophylla*	33	0	0	0	2	31
		Cheilanthes micropteris	19	0	1	4	3	11
		Argyrochosma nivea var. *nivea*	14	0	0	2	3	9
		Cheilanthes pilosa	6	0	0	0	4	2
		Cheilanthes buchtienii	4	0	2	2	0	0
		Argyrochosma nivea var. *flava*	4	0	0	1	0	3
Amaranthaceae	66	*Atriplex crenatifolia*	25	25	0	0	0	0
		Atriplex lampa	22	22	0	0	0	0
		Gomphrena martiana	13	13	0	0	0	0
		Gomphrena tomentosa	4	1	1	0	1	1
Nyctaginaceae	63	*Allionia incarnata*	44	7	6	23	4	4
		Boerhavia diffusa	19	9	7	2	0	1
Euphorbiaceae	48	*Jatropha excisa*	28	28	0	0	0	0
		Euphorbia sp.	14	2	1	4	4	3
		Euphorbia catamarcensis	5	2	3	0	0	0
Verbenaceae	47	*Lippia integrifolia*	25	0	2	2	2	19
		Lantana grisebacii	13	0	0	0	6	7
		Lippia turbinata	4	2	0	2	0	0
		Mulguraea aspera	4	0	0	1	3	0
Juncaceae	30	*Juncus acutus*	30	30	0	0	0	0

Malvaceae	28	*Lecanophora* sp.	25	4	9	2	4	6
		Herissantia crispa	3	2	0	1	0	0
Bromeliaceae	18	*Deuterocohnia schreiteri*	18	0	2	4	4	8
Boraginaceae	13	*Euploca chrysantha*	12	3	5	3	0	1
Portulacaceae	11	*Portulaca oleracea*	4	4	0	0	0	0
		Portulaca grandiflora	4	2	0	1	1	0
		Portulaca echinosperma	3	1	1	0	0	1

were included in diversity analysis as morphospecies but not in growth form analysis (see supplementary material).

Considering growth form, herbaceous plants represented almost 55% of all species (68) and 32.9% of total abundance. Shrubs and subshrubs encompassed 26.4% (33) of the species and 50.7% of total abundance, while 8.8% of the species are succulents – including succulent herbs (6), subshrubs (4) and trees (1) – and the remaining 7.2% of the species (9) are trees, with 12.2% and 4.2% of the total abundance respectively (see supplementary material).

Something to highlight is that all abundant species were also widely distributed along the altitudinal gradient and, although with variable abundances, many were present in all altitudinal bands (Tab. 1; and see appendix table 1 in supplementary material). The most frequent between them are *Opuntia sulphurea* (present in 33 sampling units), *Bulnesia schickendantzii* (33), *Aristida adscensionis* (31), *Lycium tenuispinosum* (30), *Trichocereus terscheckii* (26) and *Pectis sessiliflora* (24).

Total species abundance increased with altitude (Fig. 2a). Abundance varied from 745 records in band 1700 to 1316 in band 2500. There are some differences among altitudinal bands in the abundance of growth forms (Fig. 2). The abundance of trees showed a negative correlation with altitude (rho = -0.64, p = 9.5E-06) while the abundance of shrubs was positively correlated (rho = 0.65, p = 4.8E-06, Fig. 2c and 2d). The abundances of herbaceous and succulents showed no correlation with altitude.

The abundance of species and families also showed differences among altitudinal bands (Tab. 1). Some of the abundant species were present in three (*Prosopis torquata* and *Arquita trichocarpa*) or four (*Aristida adscensionis* and *Bulnesia schickendantzii*) altitudinal bands, while others showed a gradual decrease in abundance (such as *Senna aphila*, which was more abundant in lower elevations). Some species presented more restricted distribution along an altitudinal gradient in the study site (*Flourensia fiebriggi* and *Gochnatia glutinosa*, present in 2300 and 2500 bands). Some species were registered only in one band, being the most frequent *Atamisquea emarginata*, *Atriplex lampa*, *Atriplex crenatifolia*, and *Echinopsis leucantha* in band 1700, *Setaria parvifolia* in 2100 and *Myriopteris aurea* in 2500. From all 125 species, 43 (34,4%) were registered only once.

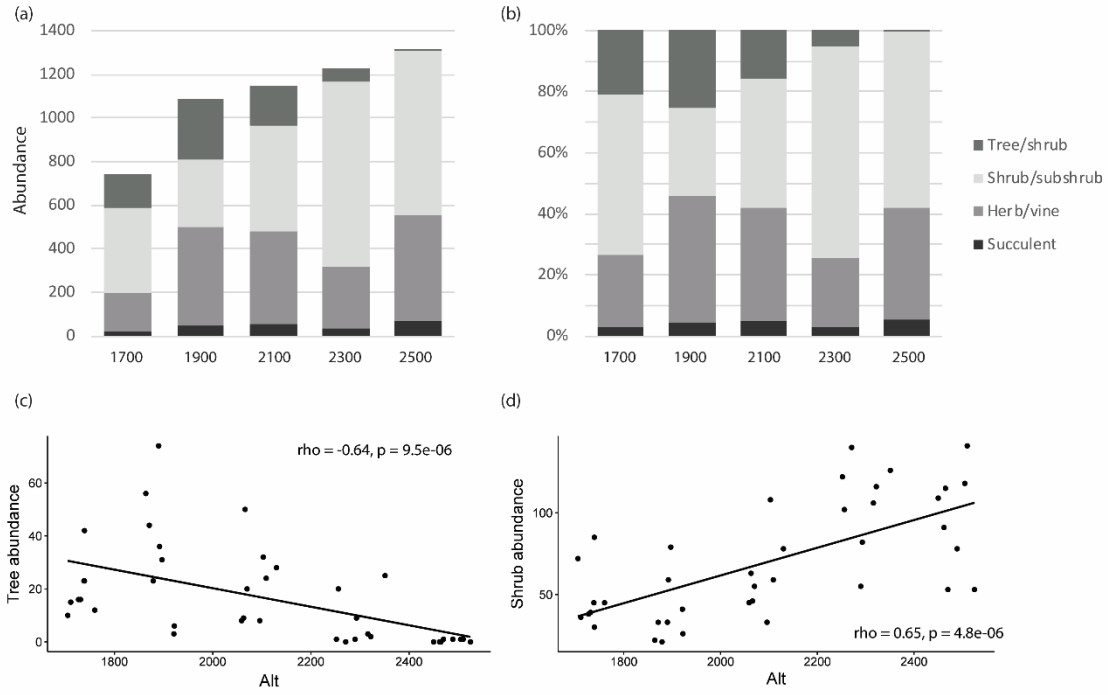

Fig. 2. Plant growth forms in in Sierra de Quilmes (Argentinian Monte Desert). Above, bar charts showing (a) plant growth form abundances, and (b) proportional abundances in each altitudinal band. Succulent category includes succulent herbs, subshrubs and trees. Below, correlation between altitude and growth form abundances, using Spearman's rank correlation coefficient. Only (c) tree abundance and (d) shrub abundance showed significant correlation with altitude. Rho and p values are shown in the plot.

The partitions of each band's diversity of order 0, 1 and 2 are represented in Fig. 3 and diversity values are synthesized in Tab. 2. The graphical representation allows to visually compare band gamma diversities and the proportion of diversity explained by within sampling unit diversity and by among sampling units' diversities. All measures of diversity are consistently lower in Band 1900 than in other bands. It is notorious the higher beta component of 1700 band diversity when compared to other bands.

Band gamma diversity profiles are presented in Fig. 4, where it is possible to see that difference in diversity between bands depends on the way it is measured, in this case, on the order of de diversity. Bands can't be ranked based on their gamma diversity because their profiles intersect. Only band 1900 was consistently less diverse, regardless of the weight given to rare species. The band 2100 is poorer than others, except 1900, when woody species are considered. Anyways, profiles intercept in most cases between $q = 0$ and $q = 1$ values, excepting 2300 and 2500 herbaceous plants profiles, showing that patterns of diversity variation along elevation are similar for typical species ($q = 1$) and for dominant species ($q = 2$), in terms of Chao et al. (2014). In both cases, diversity is higher at 1700, the lowest band, and 2300, the second highest.

Results of linear and polynomial regressions are presented in Tab. 3 and scatter plots

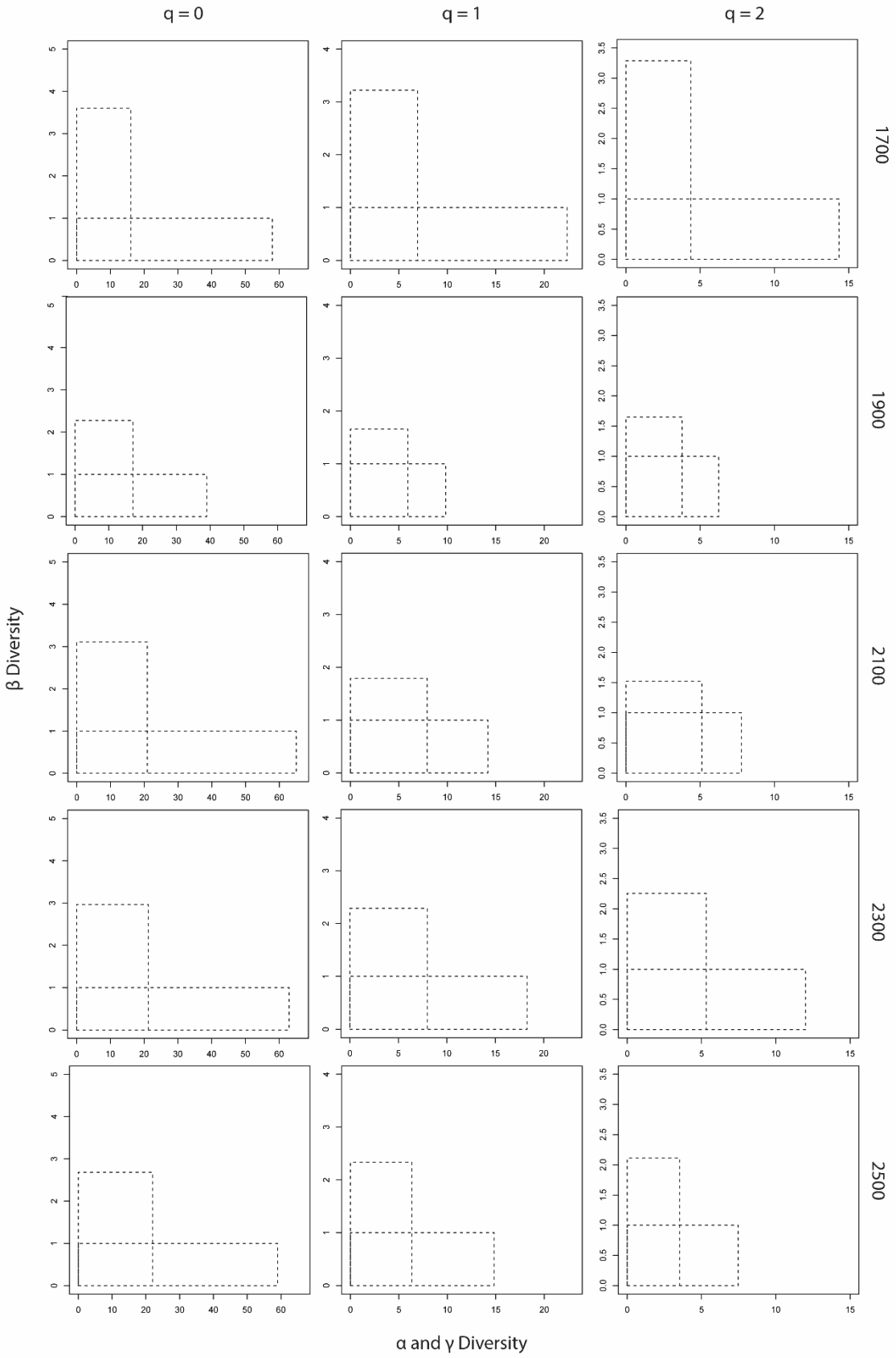

Fig. 3. Diversity partition plots of each altitudinal band diversity of order 0, 1 and 2. Alpha and gamma diversity are represented in the x axis, and b diversity in the y axis. In each plot, the long rectangle of height 1 represents band gamma diversity and the narrower and higher rectangle has the same area and represents the partition in alpha (its width) and beta diversity (length).

Tab. 2. plant Diversity values of altitudinal bands of Sierra de Quilmes (Argentinian Monte Desert). Hill numbers were used to calculate alpha, beta and gamma diversity of order 0, 1 and 2 of each band.

Band	$^0D_\alpha$	$^1D_\alpha$	$^2D_\alpha$	$^0D_\gamma$	$^1D_\gamma$	$^2D_\gamma$	$^0D_\beta$	$^1D_\beta$	$^2D_\beta$
1700	16.13	6.95	4.36	58.00	22.37	14.34	3.60	3.22	3.29
1900	17.13	5.93	3.79	39.00	9.85	6.25	2.28	1.66	1.65
2100	20.75	7.91	5.11	63.00	14.12	7.78	3.03	1.78	1.52
2300	21.25	7.99	5.32	63.00	18.29	12.00	2.96	2.29	2.26
2500	22.00	6.35	3.54	59.00	14.83	7.47	2.68	2.34	2.11

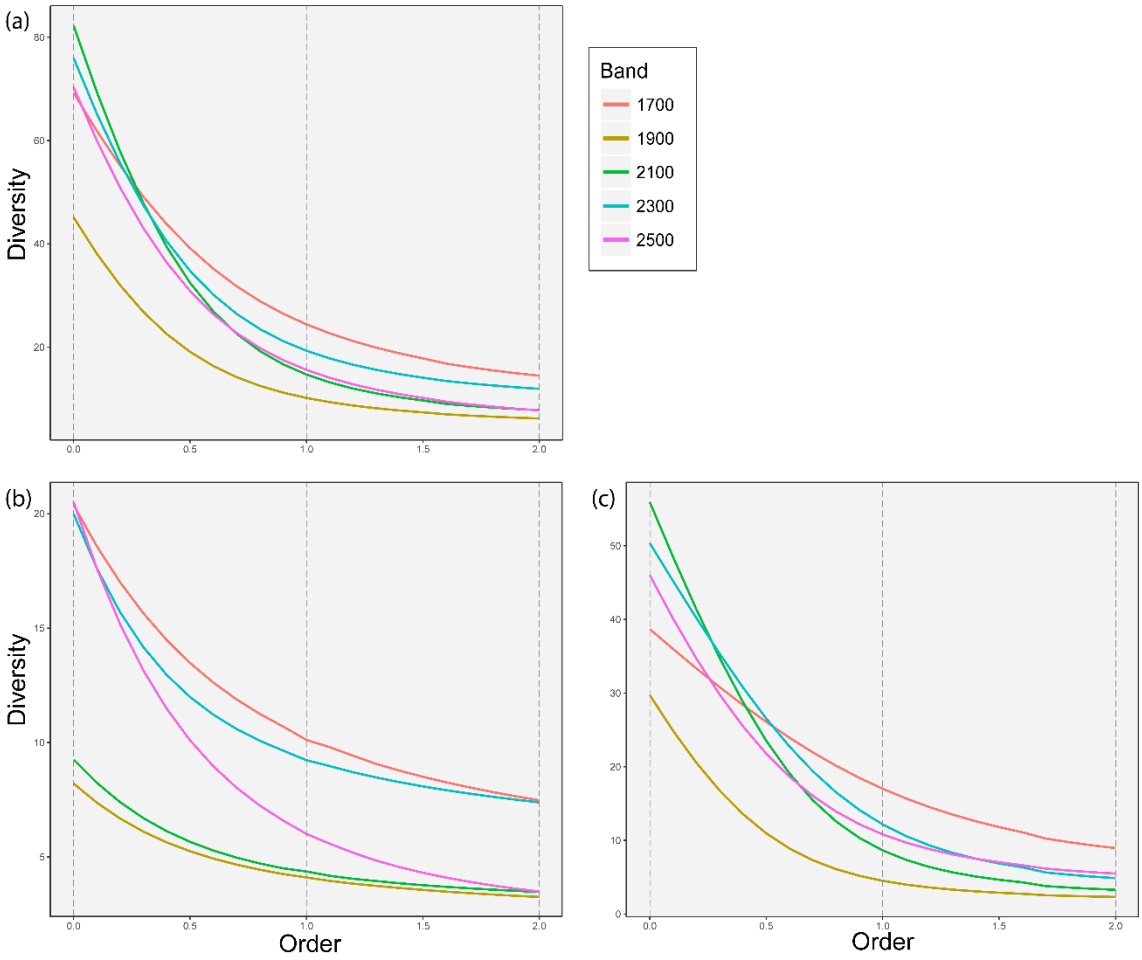

Fig 4. Plant gamma diversity profiles of altitudinal bands in Sierra de Quilmes, in Argentinian Monte Desert, considering (a) all plants, (b) woody plants and (c) herbaceous plants, calculated from Hill series. The dotted lines cross the profiles in *q* values of 0, 1, 2.

in Fig. 5. From all fitted models, only the one for all plants $^1D_\alpha$ data was not significantly different from null model. Woody plants $^1D_\alpha$ and woody plants $^2D_\alpha$ polynomial models presented the highest R^2 values (see Tab. 3), accounting respectively for 32% and 34% of the variance of the data. Even when almost all models were found to be significantly different from null models, most of them present very low values of R^2 indicating poor fit to the data. It is worth noting that, although with low R^2, $^0D_\alpha$ relation with altitude is better described by a simple linear model, with increased diversity with altitude, while $^1D_\alpha$ and $^2D_\alpha$ data better adjusted to third degree polynomial models with higher diversity values at the lowest and at

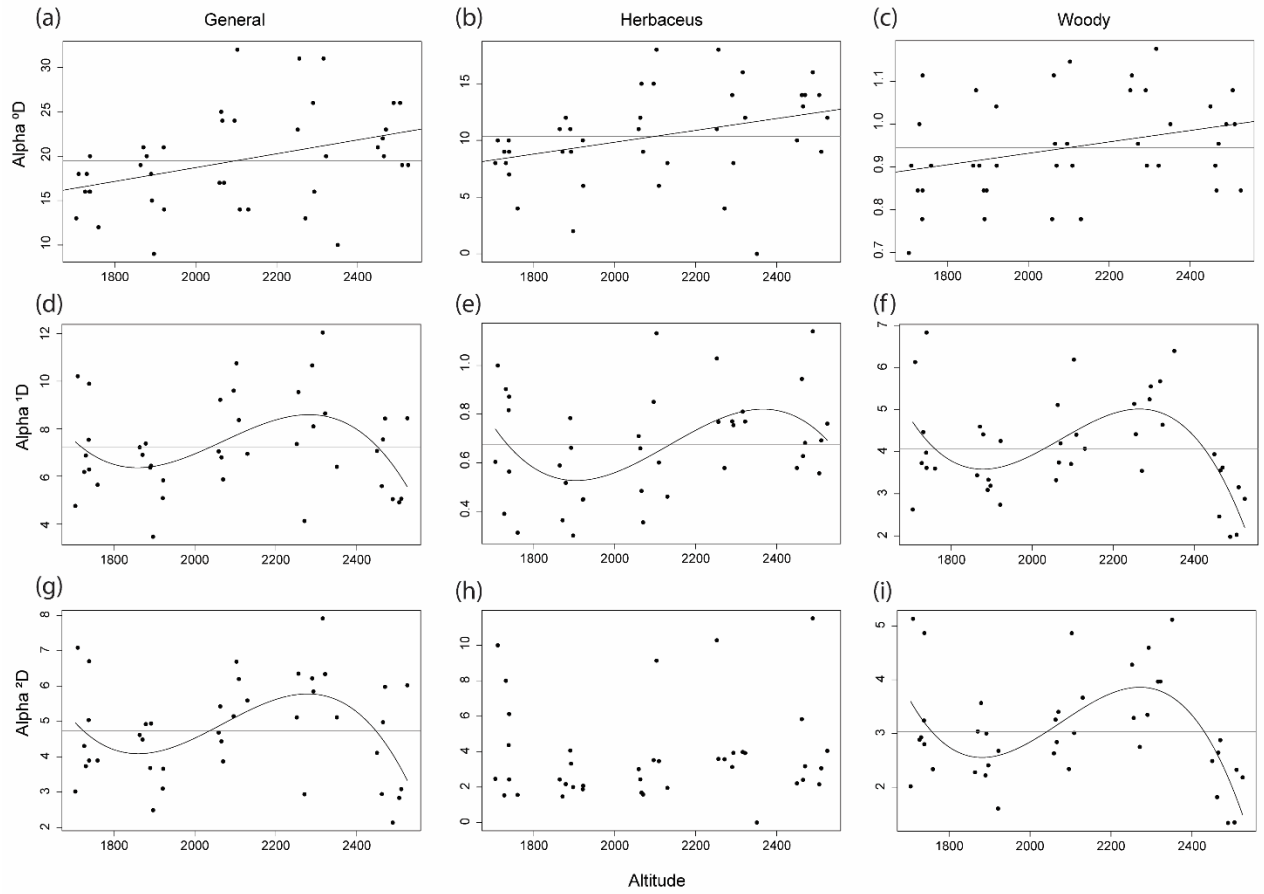

Fig. 5. Relationship between altitude (m.a.s.l.) and different measures of diversity and differentiation, measured considering all plants (first column: a, d, g, j), herbaceous plants (second column: b, e, h) and woody plants (third column: c, f, i). Alpha diversity is measured with Hill numbers of order 0 (^0D, first row), order 1 (^1D, second row) and order 2 (^2D, third row), while (j) shows the relationship between altitude and Horn index as a measure of within-band differentiation. Fitted lines are displayed only when significant difference was found between the chosen model fit and a null model fit. Diversity in (c) and (e) was log-transformed.

Tab. 3. Results of simple linear and polynomial models testing the effect of altitude on alpha diversity of order 0, 1 and 2 considering all plants, herbaceous plants and woody plants sampled in Sierra de Quilmes (Argentinian Monte Desert). F statistics (and P values) compare the mean square for the row to the residual mean square.

Response variable		F	F Pr(>F)	R^2	p-value	Intercept	Coef. 1	Coef. 2	Coef. 3
$^0D_\alpha$	All	6.794	1.30E-02	0.1294	0.0129	3.127	0.008	-	-
	Herb	4.162	4.84E-02	0.1027	0.0247	-0.596	0.005	-	-
	Woody	4.162	4.84E-02	0.0749	0.0483	0.665	0.000	-	-
$^1D_\alpha$	All	2.727	5.83E-02	0.1173	0.0583	7.237	0.866	-2.607	-4.474
	Herb	2.905	4.84E-02	0.1307	0.0483	0.674	0.352	0.175	-0.445
	Woody	7.335	5.85E-04	0.3277	5.85E-04	0.674	0.352	0.175	-0.445
$^2D_\alpha$	All	3.485	2.55E-02	0.1605	0.02553	4.739	0.403	-2.091	-3.530
	Woody	7.780	3.95E-04	0.3428	0.00039	3.033	-0.803	-1.655	-3.364

intermediate altitudes. No model was fitted to Herbs $^2D_\alpha$ data because they didn't conform normal distribution even after transformation. Woody plants $^0D_\alpha$ and Herbaceous plants $^1D_\alpha$ were log-transformed. In a general way, residual diagnosis show that linear models seem to adequate well to our data (see supplementary material).

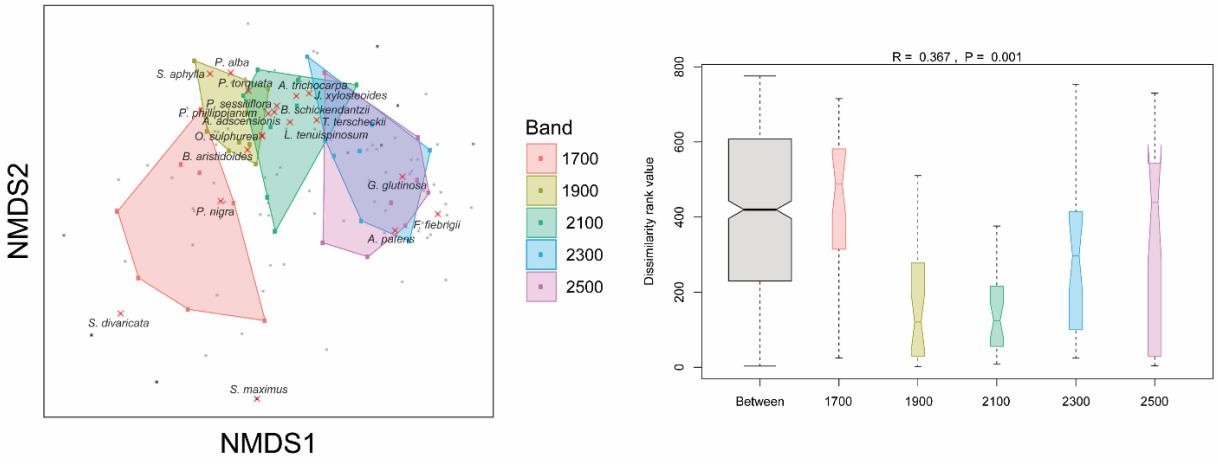

Fig 6. Ordination on plant species composition of 40 sampling units along altitudinal gradient in Sierra de Quilmes (Argentinian Monte Desert). (a) NMDS plot based on Horn index dissimilarity matrix (Dimensions: 2; Stress: 0.225412). Convex hulls were drawn to facilitate altitudinal bands visualization. The most abundant species are also shown. (b) Analysis of similarities (ANOSIM) plot showing dissimilarity among and within bands. Bold horizontal bars in box show median; whiskers extend to the most extreme data point (the range times the interquartile range from the box); width of bars represents sample size. ANOSIM statistic R and statistical significance are shown in the plot. R is a difference of mean ranks among groups and within groups; values close to 1 mean high separation among levels (in this case, bands), and a value of 0 indicates completely random grouping.

Species differentiation analysis showed that dissimilarity among bands is higher than dissimilarity within bands (ANOSIM R = 0.367, p = 0.001, Fig. 6b). This differentiation is observable in the ordination plot (Fig. 6.), where the arrangement displayed by the convex hulls and sampling units along the NMDS 1 reflects that communities differentiation occurs gradually along the altitudinal gradient. The convex hull size of 1700 band in the ordination, as well as the position of its boxplot in the anosim plot, represented its highest D_{β}. Despite the differentiation among bands, R value is relatively low, considering that 0 means completely random grouping and 1 complete separation among groups. This manifests in the partial overlap among band convex hulls in the ordination plot (Fig. 6).

Discussion

We found altitude was positively correlated with shrub/subshrub abundance and negatively correlated with tree abundance. This is consistent with previous descriptions of the vegetation in High Monte where xerophytic shrubs steppes are the dominant physiognomy vegetation type, while *Prosopis* open forests occupy basin floors and lower alluvial fans (Morello 1958). We excluded *Prosopis* forests of the sampling as they are azonal communities, but the colonization of steppes by some tree individuals can explain

their occurrence in lowland steppes. In fact, most of the *Prosopis* individuals we sampled were young trees. Morello (1958) described an increase in soil cover along the slopes, with upper slopes showing high-cover (>50%) shrubby steppes associated with higher precipitation and coarser soil textures.

We found that different measures of diversity exhibit different patterns along the altitudinal gradient. While trends point to an increase in ${}^{0}D$ (richness) with altitude, ${}^{1}D$ and ${}^{2}D$ peaked in the lowest band and in intermediate altitudes, particularly when analyzing diversity of woody plants, for which effect sizes were higher. In any case, we found the effect size of altitude on plant diversity values is low for our study area, reinforcing the notion that there are several other factors, varying independently of altitude, that affect the distribution of plant species and lead to high heterogeneity of plant communities in the Monte Desert (Acebes et al. 2010, Bisigato et al, 2008). Some of these factors are discussed in the next paragraphs.

Diversity partition shows that much of the gamma diversity of the 1700 band is explained by beta diversity, i.e. differentiation among sites. When sampling units are overlapped with the geomorphological map of the study site (see Peña Monné & Sampietro Vattuone 2016), we find out that the 1700 band is the one that represents the highest geomorphological diversity: H2 and H3 alluvial fans and two functional sectors – a channel in active stream and a fluvial aeolian mantle –, both active and with their surfaces being currently remodeled by the action of water and wind respectively. On the other hand, sampling units of the 1900 band, the poorest in most diversity measures, were all taken on H2 alluvial fans. As the different geomorphological units imply gradients in factors that affect plant composition, such as soil texture, water availability and temperature (Bisigato et al 2009), it is probable that part of the band beta diversity differences is related to them. Besides, edaphic variability – described by Morello (1958) and Cabrera (1971) as determinant of azonal communities – and human activity, are certainly sources of additional heterogeneity in 1700 band.

Soil characteristics like high salt or sand content are also important factors affecting floristic composition, with different species associated to different soils contents (Bisigato et al. 2009, Beeskow et al. 1987, González Loyarte et al. 1990, Morello 1958, Villagra et al. 2004). Such variation may occur at the local scale. Spatial scale variation of soil properties may be smaller than our sampling unit size, which implies species associated to different soil types being sampled in a single sampling unit and contributing to alpha diversity.

Now, leaving aside the lower band, we can see that diversity pattern in the rest of the gradient is similar to hump-shaped patterns reported by other studies in arid and semi-arid

mountain environments (Brinkmann et al. 2009, Sang 2008, Hegazy et al. 1998, Jobbágy et al. 1996). Altitudinal gradients encompass a series of climatic and environmental factors that are correlated with each other and generate a problem for hypothesis testing (Nogués Bravo et al. 2008). Thus, most of the studies address the relationship of this variables with diversity patterns a posteriori, in an exploratory way. Hegazy et al. (1998) attribute the hump-shaped pattern to climatic differences, substrate discontinuities and mountainous escarpment along the altitudinal gradient. Brinkmann et al. (2009) attribute it to the higher heterogeneity in topography in the intermediate zone, and it more balanced climate, cooler and more humid than in lowlands. Jobbágy et al. (1996) explores the importance of water availability in explaining floristic and diversity gradients in semiarid regions, highlighting that in complex landscapes, rainfall gradients are not the only factor to be considered. In mountain regions, water availability was related to rainfall, slope angle, slope aspect and altitude. For our study region, there are some descriptions of rainfall, soil particle size and slope angle relationship with floristic and structural vegetation diversity (Bisigato et al. 2009), but the ways in which climatic, edaphic and geomorphological factors vary with altitude, interact with each other and affect water availability and plant diversity still need to be assessed. Cabido et al. (1993) reported changes in vegetation composition and a reduction in diversity along a humidity gradient from central Chaco to Monte Desert. Nevertheless, this gradient did not involve altitudinal variation, allowing to more easily link precipitation with water availability, as suggested by Joggáby et al. (1996).

Acebes et al. (2010) analyzed floristic composition in relation with small-scale variables such as slope, rock cover, bare ground and litter in a hyper-arid sector of the central Monte. They found it was not possible to segregate distinct communities due to internal heterogeneity and large-scale homogeneity and overlap between different sites. In this study we found that, although species composition differences among sampling units in each band was high, the differentiation among bands was higher. Two main differences between their study site and ours might be related to this difference: aridity, as they sampled an hyper-arid region, and anthropogenic disturbance, as they study was performed in a protected area, while our study site is subjected to many disturbances that might affect heterogeneity, mainly grazing. Nonetheless, effects of grazing on vegetation heterogeneity are not clear. Whether it increases or decreases vegetation similarities among communities might depend on grazing pressure strength (Bisigato et al. 2009, Villagra et al 2009).

Conclusions

In this study we found some patterns in vegetation growth form and diversity that can be related to the altitudinal gradient in High Monte Desert. We observed a decrease in tree abundance and an increase in shrub/subshrub abundance with elevation. While diversity of order 0 shows a linear increase with altitude, diversity of order 1 and 2 patterns show peaks at the lowest and at intermediate altitudes. Anyway, the effect size of altitude on diversity was generally low, showing that probably no single variable can be regarded as a good predictor of plant diversity. A high amount of the 1700 band gamma diversity is due to high beta diversity, that can be explained by diverse additional sources of variation such as geomorphology and soil features. The rest of the gradient adjusts to the hump-shaped pattern frequently cited in plant diversity along altitudinal gradient studies and can be related to factors correlated to altitudinal gradient such as climatic variables, mainly precipitation, soil texture and slope angle.

Further studies are required in order to understand how factors correlated with altitude and factors independent of altitude, like some soil characteristics and grazing, interact with each other and affect vegetation patterns of diversity in Monte Desert.

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3. CONSIDERACIONES FINALES

En el presente estudio encontramos algunos patrones en las formas de crecimiento de la vegetación relacionadas al gradiente altitudinal: se observa una disminución en la abundancia de arbóreas y un aumento en la abundancia de arbustivas/subarbustivas con la elevación. Mientras la diversidad de orden 0 presenta un leve aumento lineal con la altitud, los patrones de diversidad de orden 1 y 2 exhiben picos en las elevaciones más bajas y en elevaciones intermedias. Sin embargo, el tamaño del efecto de la altitud sobre la diversidad fue de modo general muy bajo, y los residuos grandes, demostrando que probablemente no haya una única variable que pueda ser considerada un buen predictor de la diversidad vegetal de la zona. Una buena proporción de la diversidad beta de la banda 1700 se debe a la alta diversidad beta, que puede ser explicada por diversas fuentes adicionales de variación, tales como la geomorfología y características del suelo. El resto del gradiente se ajusta a la curva en forma de joroba que es frecuentemente reportada en estudios de diversidad vegetal a través de gradientes de altitud, y puede sr relacionada con factores que covarían con la altitud, como variables climáticas, principalmente la precipitación, la textura de suelos y el ángulo de la pendiente.

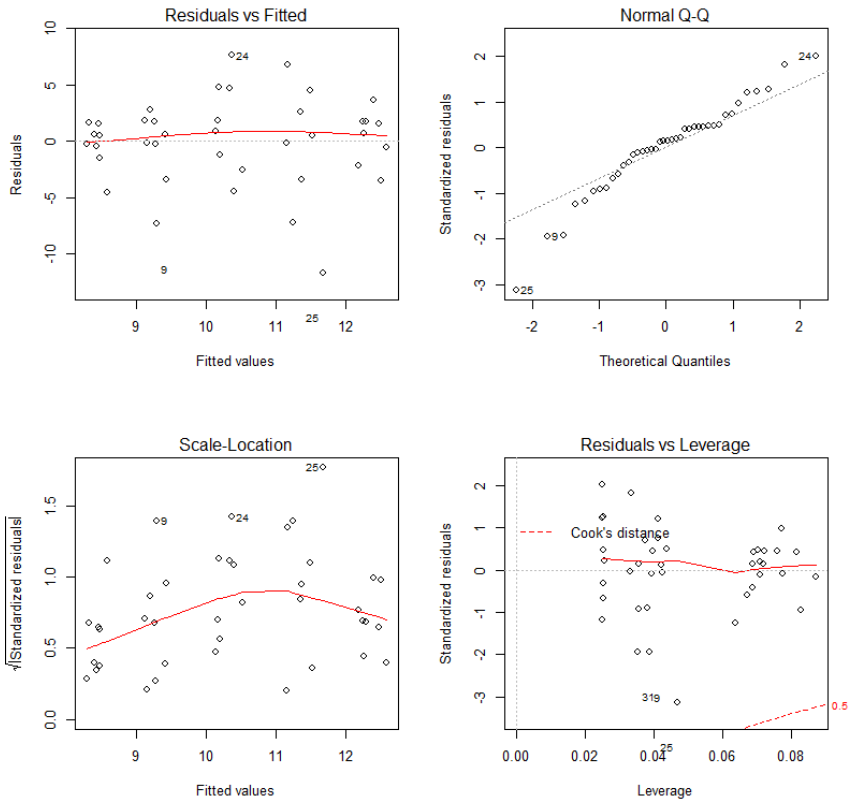
En un próximo trabajo, pretendemos evaluar cómo algunas variables climáticas, edáficas y geomorfológicas que son descritas por otros autores como relevantes para la vegetación, así como disturbios antropogénicos tales como el pastoreo, interactúan entre sí y afectan los patrones de vegetación aquí descritos.

ANEXO: MATERIAL SUPLEMENTAR

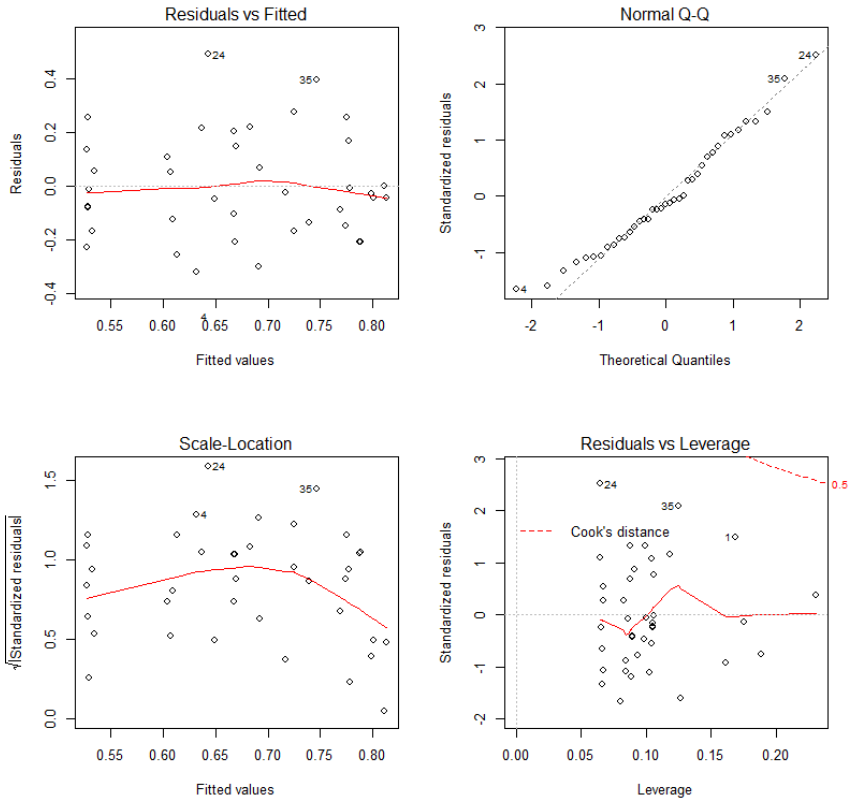
1 Plant pecies registered in Sierra de Quilmes, Monte Desert

Family	Total Ab.	Species	Total Ab.	1700	1900	2100	2300	2500
Acanthaceae	174	*Justicia tweediana*	79	0	0	0	61	18
		Justicia xylosteoides	95	2	8	29	56	0
		Acanthaceae 1	1	0	0	0	1	0
Amaranthaceae	66	*Gomphrena martiana*	13	13	0	0	0	0
		Alternanthera pungens	1	0	0	1	0	0
		Atriplex crenatifolia	25	25	0	0	0	0
		Atriplex lampa	22	22	0	0	0	0
		Gomphrena sp.	1	1	0	0	0	0
		Gomphrena tomentosa	4	1	1	0	1	1
Amaryllidaceae	4	*Zephyranthes* sp.	1	1	0	0	0	0
		Nothoscordum gracile	3	0	0	1	1	1
Asteraceae	1015	*Bidens* sp.	5	0	0	0	5	0
		Acanthostyles buniifolium	1	0	0	0	0	1
		Austrobrickellia patens	83	0	0	0	31	52
		Baccharis salicifolia	81	11	0	0	13	57
		Bidens subalternans	35	3	1	4	12	15
		Flourensia fiebrigii	482	0	0	0	87	395
		Gochnatia glutinosa	200	0	0	0	134	66
		Pectis sessiliflora	110	4	16	63	11	16
		Senecio pinnatus	4	0	0	1	1	2
		Senecio sp.	2	0	0	2	0	0
		Zinnia peruviana	12	0	0	3	5	4
		Proustia cunneifolia	2	0	0	0	0	2
Boraginaceae	13	*Euploca mendocina*	1	0	1	0	0	0
		Euploca chrysantha	12	3	5	3	0	1
		Phacelia sp.	1	0	0	0	1	0
Bromeliaceae	18	*Deuterocohnia schreiteri*	18	0	2	4	4	8
Cactaceae	241	*Echinopsis leucantha*	1	1	0	0	0	0
		Acanthocalycium glaucum	1	0	0	1	0	0
		Acanthocalycium thionanthum	11	0	2	5	2	2
		Cereus aethiops	7	2	3	2	0	0
		Gymnocalycium saglionis	5	1	1	3	0	0
		Gymnocalycium spegazzinii	11	3	5	3	0	0
		Opuntia sulphurea	91	17	31	28	9	6
		Parodia sp.	7	0	0	1	3	3
		Parodia microsperma	1	0	0	1	0	0
		Tephrocactus weberi	1	0	0	1	0	0
		Trichocereus terscheckii	82	1	5	15	10	51
		Tunilla corrugata	23	0	2	0	12	9
Capparaceae	6	*Atamisquea emarginata*	6	6	0	0	0	0
Celastraceae	1	*Maytenus viscifolia*	1	0	0	0	1	0
Chenopodiaceae	131	*Suaeda divaricata*	131	131	0	0	0	0
Commelinaceae	3	*Commelina erecta*	3	2	0	0	1	0
Convolvulaceae	1	Convolvulaceae *1*	1	0	0	0	1	0
Cucurbitaceae	1	*Cucurbitella asperata*	1	1	0	0	0	0
Ephedraceae	1	*Ephedra triandra*	1	0	0	1	0	0
Euphorbiaceae	48	*Jatropha* sp.	28	28	0	0	0	0
		Euphorbia catamarcensis	5	2	3	0	0	0
		Euphorbia serpens	1	1	0	0	0	0
		Euphorbia sp.	14	2	1	4	4	3
Fabaceae	1305	*Geoffroea decorticans*	6	6	0	0	0	0
		Arquita trichocarpa	466	0	48	135	178	105
		Erythrostemon gilliesii	2	2	0	0	0	0
		Parkinsonia praecox	37	29	4	3	1	0
		Prosopis alba	20	0	3	17	0	0
		Prosopis nigra	75	47	7	15	3	3
		Prosopis torquata	519	59	259	144	56	1
		Senna aphylla	179	67	73	21	18	0
		Vachellia aroma	1	1	0	0	0	0
Geraniaceae	2	*Geranium* sp.	2	0	0	1	0	1
Juncaceae	30	*Juncus acutus*	30	30	0	0	0	0
Lamiaceae	5	*Salvia cuspidata*	5	0	0	1	2	2
Loasaceae	3	*Mentzelia parvifolia*	3	0	0	1	1	1
Malvaceae	28	*Herissantia crispa*	3	2	0	1	0	0
Malvaceae		*Lecanophora* sp.	25	4	9	2	4	6
Martyniaceae	2	*Craniolaria integrifolia*	1	1	0	0	0	0
Martyniaceae		*Ibicella parodii*	1	1	0	0	0	0
Nyctaginaceae	63	*Boerhavia diffusa*	19	9	7	2	0	1

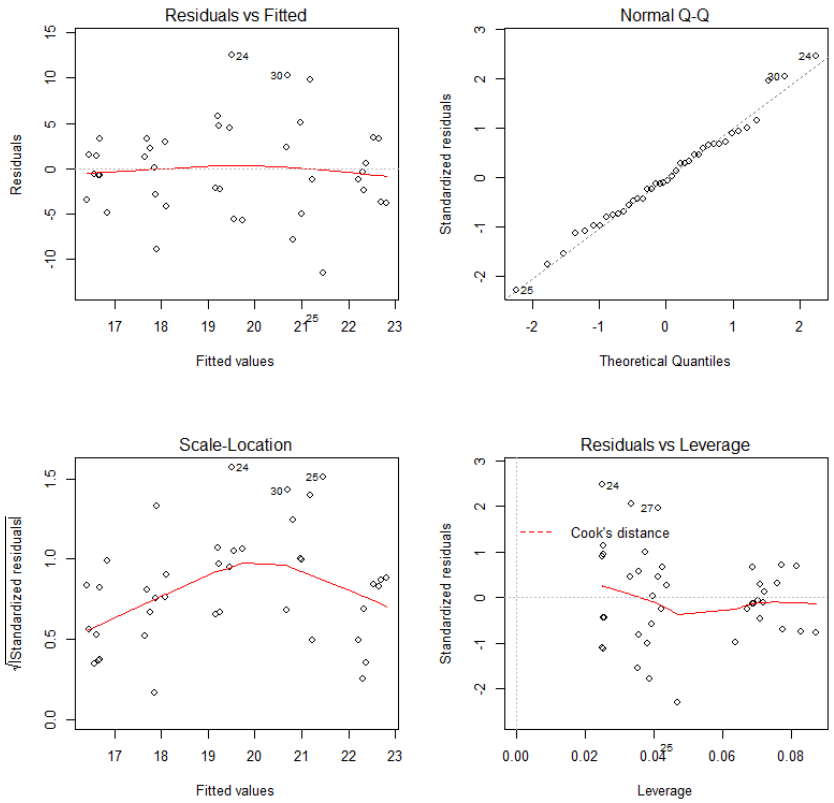
		Allionia incarnata	44	7	6	23	4	4
Poaceae	1299	*Sporobolus maximus*	16	16	0	0	0	0
		Aristida adscensionis	767	6	292	231	109	129
		Bouteloua aristidoides	143	46	75	4	3	15
		Digitaria californica	3	0	0	1	0	2
		Eragrostis cilianensis	3	0	0	2	0	1
		Leptochloa sp.	1	0	0	1	0	0
		Muhlenbergia asperifolia	9	0	3	4	2	0
		Munroa argentina	5	0	2	2	0	1
		Jarava sp.	242	0	0	22	67	153
		Pappophorum sp.	2	0	0	1	0	1
		Pappophorum phillippianum	92	5	21	20	6	40
		Setaria parviflora	3	0	0	3	0	0
		Tragus andicola	13	4	1	5	1	2
Polygalaceae	4	*Monnina* sp.	4	0	0	0	4	0
Polypodiaceae	1	*Pleopeltis pinnatifida*	1	0	0	0	1	0
Portulacaceae	11	*Portulaca oleracea*	4	4	0	0	0	0
		Portulaca echinosperma	3	1	1	0	0	1
		Portulaca grandiflora	4	2	0	1	1	0
Pteridaceae	82	*Myriopteris aurea*	2	0	0	0	0	2
		Argyrochosma sp. 1	14	0	0	2	3	9
		Cheilanthes buchtienii	4	0	2	2	0	0
		Cheilanthes micropteris	19	0	1	4	3	11
		Cheilanthes pilosa	6	0	0	0	4	2
		Myriopteris myriophylla	33	0	0	0	2	31
		Argyrochosma sp. 2	4	0	0	1	0	3
Rubiaceae	8	*Mitracarpus megapotamicus*	8	0	0	1	3	4
Scrophulariaceae	7	*Buddleja mendozensis*	7	0	0	0	5	2
Solanaceae	140	*Solanum tweedianum*	1	0	0	0	1	0
		Lycium chilense	2	2	0	0	0	0
		Lycium tenuispinosum	124	21	24	21	54	4
		Nicotiana glauca	4	4	0	0	0	0
		Solanum argentinum	2	1	0	0	0	1
		Solanum echegarayi	2	0	0	0	1	1
		Solanum sp. 1	1	0	0	0	0	1
		Solanum sp. 2	1	0	0	1	0	0
		Solanum sp. 3	1	0	0	0	1	0
		Solanum sp. 4	1	0	0	0	1	0
		solanum sp. 5	1	0	0	1	0	0
Tamaricaceae	11	*Tamarix ramosissima*	11	11	0	0	0	0
Verbenaceae	47	*Aloysia castellanosii*	1	0	0	1	0	0
		Lantana grisebacii	13	0	0	0	6	7
		Lippia integrifolia	25	0	2	2	2	19
		Lippia turbinata	4	2	0	2	0	0
		Mulguraea aspera	4	0	0	1	3	0
Zygophyllaceae	711	*Larrea cuneifolia*	5	2	3	0	0	0
		Bulnesia schickendantzii	699	65	153	263	196	22
		Tribulus terrestris	7	2	2	0	0	3
NI		NI 1	1	0	0	0	1	0
NI		NI 2	2	1	0	1	0	0
NI		NI 3	11	0	0	6	2	3
NI		NI 4	1	0	0	0	1	0
NI		NI 5	15	0	0	0	7	8
NI		NI 6	2	0	0	0	2	0
NI		NI 7	2	1	0	0	0	1



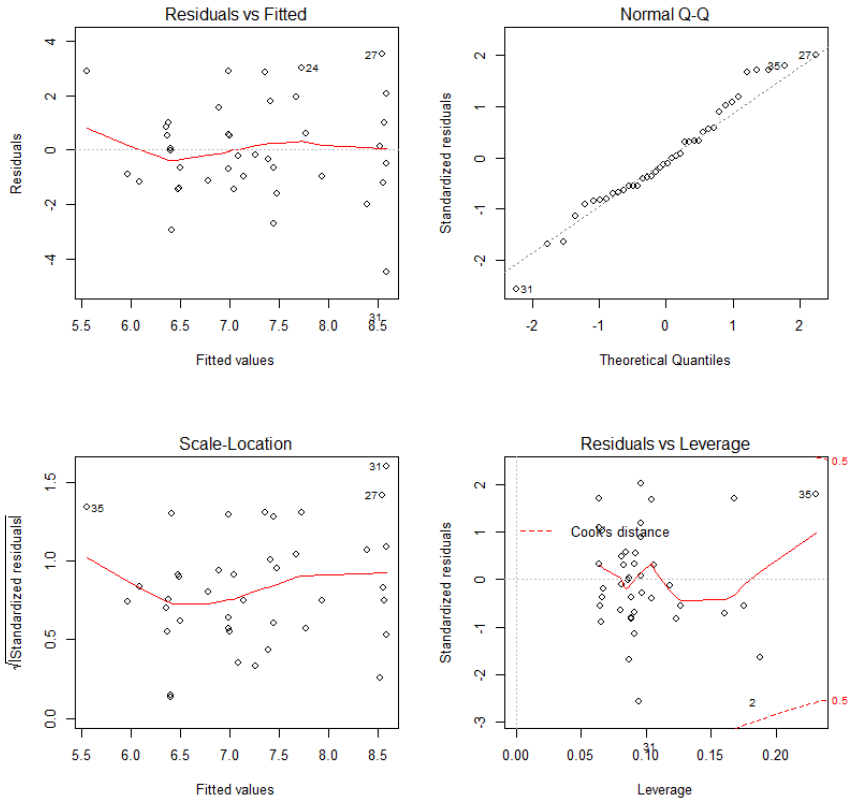
1Residual errors plot, herbaceous diversity of order 0



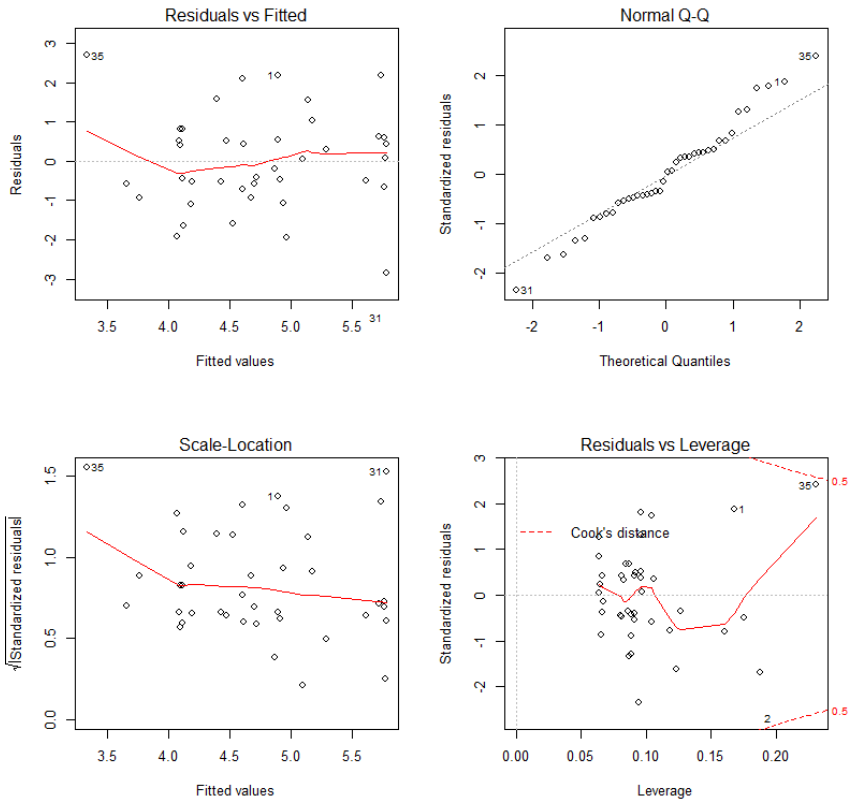
2 Residual errors plot, herbaceous diversity of order 1



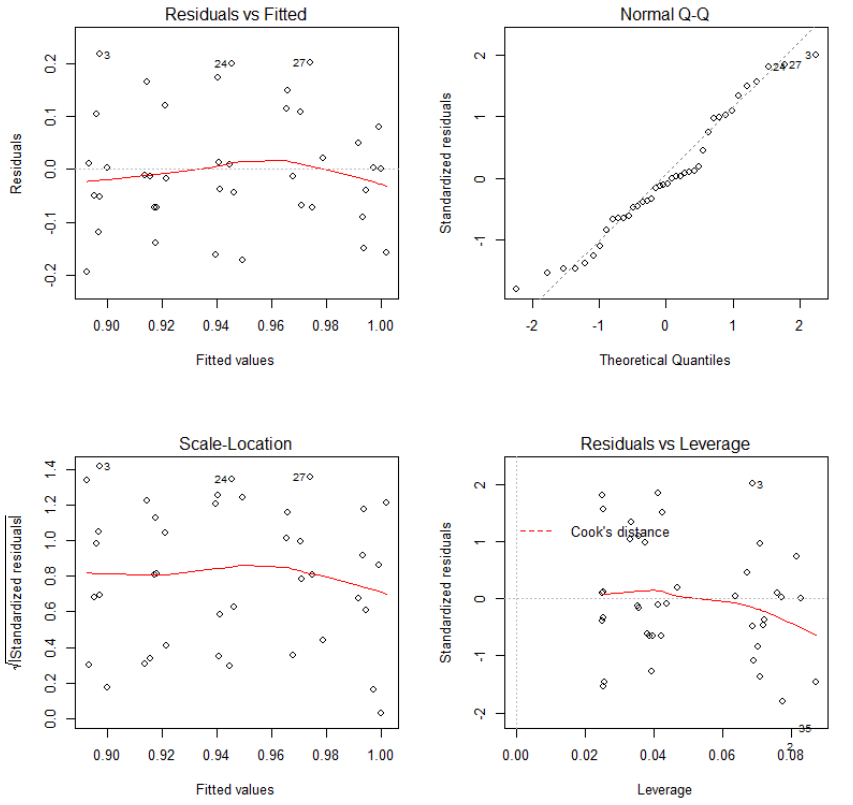
3 Residual errors plot, all plants diversity of order 0



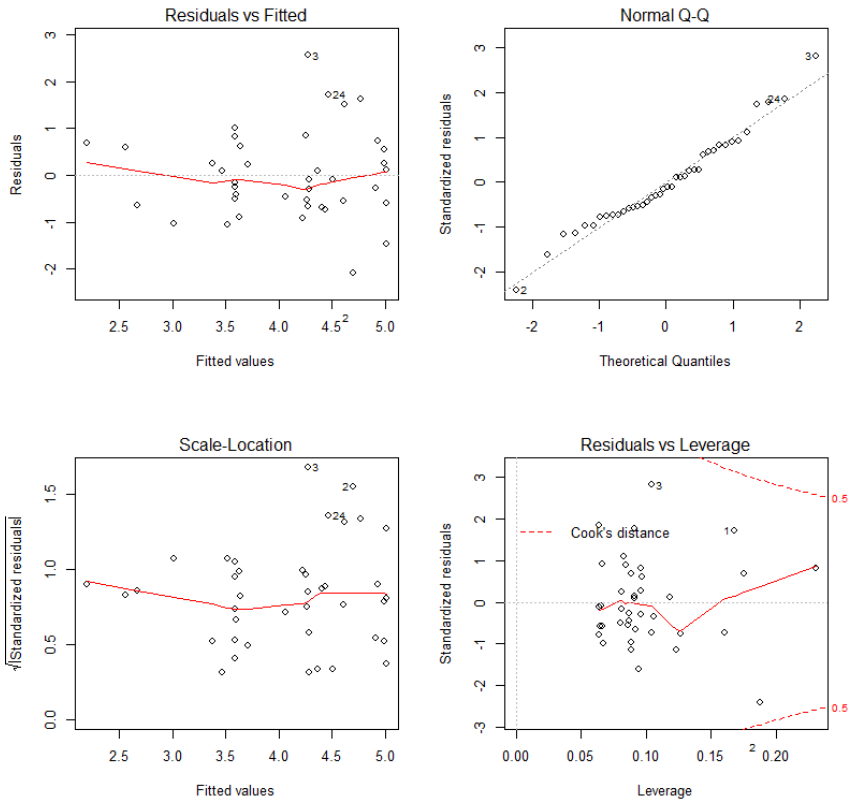
4 Residual errors plot, all plants diversity of order 1



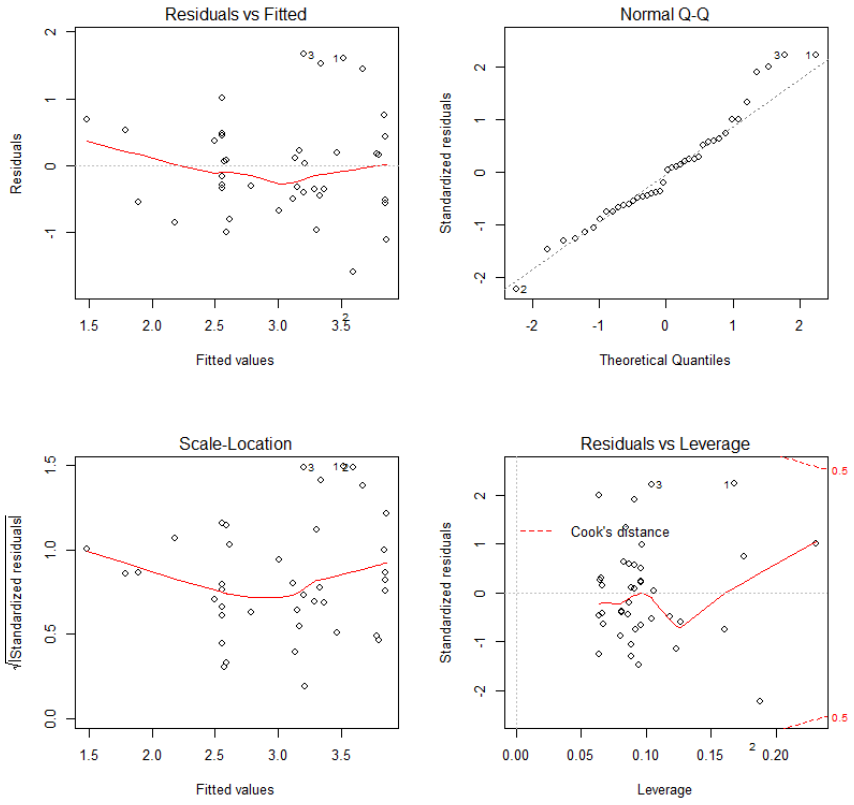
5 Residual errors plot, all plants diversity of order 2



6 Residual errors plot, woody plants diversity of order 0



7 Residual errors plot, woody plants diversity of order 1



8 Residual errors plot, woody plants diversity of order 2